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Review article

A novel bionic algorithm inspired by plant root foraging behaviors

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ABSTRACT

In this contribution, a novel bionic algorithm inspired by plant root foraging behaviors, namely artificial root foraging optimization (ARFO) algorithm, is designed and developed. The incentive mechanism of ARFO is to mimic the adaptation and randomness of plant root foraging behaviors, e.g., branching, regrowing and tropisms. A mathematical architecture is firstly designed to model the plant root foraging pattern. Under this architecture, the effects of the tropism and the self-adaptive growth behaviors are investigated. Afterward, the arithmetic realization of ARFO derived from this framework is presented in detail. In order to demonstrate the optimization performance, the proposed ARFO is benchmarked against several state-of-the-art reference algorithms on a suit of CEC 2013 and CEC 2014 functions. Computational results show a high performance of the proposed ARFO for searching a global optimum on several benchmarks, which indicates that ARFO has potential to deal with complex optimization problems.

Contents

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1. Introduction

In recent years, great development of bionic optimization algorithms based on forging behaviors has been achieved [1–4]. Foraging is a significant inherent feature of behaviors that touches virtually all aspects of ecological species, involving optimal decision-making strategies for locating, handling, and ingesting food effectively in a given environment [1,2]. As the optimal foraging theory emphasizes [5], the main purpose of the optimal decisions-making by the foraging individual or group is to maximize the foraging currency measured by the energy obtained per unit time spent foraging. Intuitively, the optimal foraging principles have demonstrated their niche in the field of bio-inspired optimization theory, which provides a close relationship between evolutionary forces in optimal foraging and distributed optimization models design [3]. For instances, artificial bee colony algorithm (ABC) [4], ant colony optimization (ACO) [6,7], and particle swarm optimization (PSO) [8] are essentially inspired from natural foraging strategies of bee, ants and birds flocking, respectively. It is worthy noted that these flexible and robust computation paradigms mainly depend on the motile foraging behaviors unique to species of social animals.

Obviously, as another important biological species, plants attract little attention in the bio-inspired optimization domain due to their specific foraging-style. In comparison to animal foraging, plant forage for environmental nutrients by means of iterative growth and constant branch, instead of taking spontaneous and independent motile actions. Furthermore, shaping spatial configuration of root system to explore heterogeneously distributed resources is essential for survival of plant species. Plant roots have evolved flexible adaptation to complex environments that they can sense environmental stimuli and use this information to adjust growth direction and lateral branching.

Plant roots demonstrate considerable morphological plasticity in response to environmental heterogeneity, including lateral branching, root biomass and tropism-based growth [9]. These developmental operations are mainly regulated by transport and signaling of plant hormone called auxin [10,11]. Consequently, plant root can appropriately avoid obstacles and explore nutrient-rich patches by adjusting its spatial configuration such as elongate length and root biomass per unit soil volume [11]. This iterative propagation progress highlights that roots have significant ability of searching for the most profitable position with natural growth strategies. Intuitively, such evolutionary principles can be modeled deliberately for develop new heuristic optimization paradigms.

However, comparing to the huge in-depth studies of other classical animal-based bionic algorithms and their wide applications (e.g., school timetabling, medical data mining) [12–15], the development and design of effective plant-based evolutionary paradigms is still a challenging issue. Fortunately, there are some existing computation models to simulate behavioral features of plant or plant roots [16–20]. For instances, the first descriptive 3-dimensional root system model is proposed with consideration of the morphogenesis of the maize roots [16]. A dynamic root system growth model based on L-systems, specially focusing on soil–root interactions, is proposed in [17]. The inherent connection of root architecture and nutrient acquisition efficiency is deliberately investigated [18], and it claims that the structure and dynamics of root system is so complex and flexible that the simulation modeling of root system development essentially needs to take account of the biophysical interactions between root tips and soil environment. As a result, the complexity of the root growth behaviors via environmental stimuli requires an explicitly accurate and systemic description not only of pure growth simulation (e.g., L-system) of each subsystem, but also of their mutual interaction and influence [19,20].

In this contribution, by combining the self-adaptive growth behaviors with the optimal foraging, a novel optimization model for global numerical optimization, namely ARFO algorithm, is developed and designed. The proposed ARFO model incorporates the branching, regrowing, mortality and tropism mechanisms of the root system. In the proposed algorithm emulating the distributed optimization process represented by the activity of plant root growth, several efficient ways to search for space optimization problems is proposed. The local search and global search using root branching and elongation (tropism) both controlled by auxin concentration during the foraging process are implemented. The random growth of lateral roots and dead root elimination mechanisms are also developed to keep the diversity and efficiency of the algorithm. Intuitively, the novelties and characteristics of ARFO are summarized below.

(1) A new foraging strategy. The root foraging model provides an open framework to utilize research in plant foraging behavioral ecology to tackle complex problems, and it simulates the plant root tropism mechanism, and sets up the dynamics mechanism of root growing rapidly toward the global optima.
(2) A new information regulation mechanism. The design of auxin-regulated mechanism resolves significant issues that how to select new root tips and branching number of roots. Particularly, the concept of nutrient concentration is essentially established, which ensures that even if the fitness of objective function is not best, the higher fitness gradient of the objective function also generates higher auxin concentration.
(3) The exploring/exploiting strategy. The regrowing operator of mainroot employs a large elongate-length unit to explore the previously unscanned regions in the search space as fast as possible. The lateral-roots implement the regrowing operator with a small elongation-length unit to perform fine-tuning exploitation of the global optimum.

The rest of the paper is organized as follows: in Section 2, the root foraging model and the implementation details of ARFO algorithm will be given. The simulation of the intrinsic foraging behaviors is implemented in Section 3. Numerical examples and comparisons with well-known algorithms are presented in Section 5 to verify the efficiency of the ARFO algorithm. Finally, some concluding remarks are provided in Section 5.

2. Root foraging model for optimization

2.1. Root foraging model

Plant roots exhibit substantial plasticity in growth in relation to environmental heterogeneity, often preferentially placing their foraging organs in nutrient-rich areas [21–25]. The concept of root foraging behavior was proposed by McNickle and Cahill based on the MVT theory [9,26]. They found that the root foraging was accomplished by the root morphological responses, which were